GENERAL ATOMIC

DIVISION OF

GENERAL DYNAMICS

JOHN JAY HOPKINS LABORATORY FOR PURE AND APPLIED SCIENCE

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GA-6642

RESEARCH ON ELEMENTAL ABUNDANCES IN METEORITIC AND TERRESTRIAL MATTER

SUMMARY PROGRESS REPORT

SEPTEMBER 1, 1964, THROUGH AUGUST 31, 1965

Contract NASw-843

National Aeronautics and Space Administration

Work done by:

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Report written by:

R. A. Schmitt

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PREVIOUS REPORTS IN THIS SERIES

GA-4782—September, October, November, 1963

GA-4997—December, 1963; January, February, 1964

GA-5303—March, April, May, 1964

GA-5594—September 1, 1963, through August 31, 1964

GA-5900—September, October, November, 1964

GA-6184—December, 1964; January, February, 1965

GA-6414—March, April, May, 1965

This summary progress report on research on elemental abundances covers the work performed under NASA Contract NASw-843 during the period from September 1, 1964, through August 31, 1965.

During the last quarter of the reporting period--from June 1, 1965, through August 31, 1965--abundances of seven elements, Na-Cu (Na, Sc, Cr, Mn, Fe, Co, and Cu), were determined by the technique of INAA (instrumental neutron activation analysis) in 25 individual chondrules separated from the Type IIIA carbonaceous chondrite Ornans (Table 1); 40 chondrules from the L-group chondrite Saratov (Table 2); 20 chondrules from the H-group chondrite Richardton (Table 3); and 20 chondrules from the H-group chondrite Miller (Table 4).

Throughout the contract year, emphasis has been directed toward abundance determinations of the elements Na-Cu in 273 individual chondrules separated from 12 chondritic meteorites, and in particular toward INAA of chondrules from carbonaceous chondrites. The ratios of the average abundances in chondrules to abundances in the respective carbonaceous Types IIIA and IIIB chondrites have been plotted in Figs. 1 and 2. (These figures may be compared with Figs. 1 and 2 of GA-5900,* which show the corresponding ratios of chondrules and matrices of Type II carbonaceous chondrites.) In Figs. 3 through 7, correlations of Fe-Co and Co-Cu have been plotted for Type IIIA and IIIB carbonaceous and other chondrites. Collation and interpretation of the presently determined abundances with previously established values for other chondrules will be reserved for a future paper on chondrule abundances.

Abundances of the seven elements Na-Cu could easily be determined in these "battleship-type" experiments, because convenient radionuclides (2.56-hr to 5.3-yr half-lives) of these elements are generated in meteoritic stony matter by thermal-neutron activation and can be subsequently measured by gamma-ray scintillation spectrometry.

Since chondritic abundances have been generally normalized to Si, abundances of the lithophilic elements Na, Sc, Cr, and Mn in chondrules will be normalized to Si. In a collaborative program with W. D. Ehmann of the University of Kentucky, we have used the General Atomic Cockroft-Walton 14-Mev neutron generator to measure the Si content in 143 individual chondrules from 8 chondritic meteorites for which the abundances of the elements Na-Cu have been measured. This collaborative program is continuing.

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*The quarterly progress report for the period ending November 30, 1964.

An attempt (described in GA-5900) was initiated to determine the Ni content, via IPAA (instrumental photonuclear activation analysis) of $Ni^{58}(\gamma, n)$37-hr Ni^{57}, of all the chondritic meteorites having known Fe and Co abundances (ascertained via INAA). In addition, Mg was measured via IPAA of $Mg^{25}(\gamma, p)$15-hr Na^{24} in some 40 chondritic meteorites. In a second attempt (described in GA-6184*) to measure selectively Ni via IPAA, a triple coincidence circuit (CC) was used. This circuit consisted basically of two single-channel analyzers (SCA) which, upon coincidence of the 0.51-Mev annihilation γ's of 37-hr Ni^{57}, opened the RCL multichannel analyzer for detection, via a 3 in. × 3 in. NaI crystal, of the 1.37-Mev γ of Ni^{57}. The observed high Ni values--higher by some 25% than those obtained by other workers--were attributed to the interference of the 1.37-Mev γ of 15-hr Na^{24}, whose level of activity far exceeded that of Ni^{57}. A "slow" CC, >2 μsec τ (resolving time), had been used for the early Ni coincidence work.

During the last quarter of the reporting period, a "fast" double and triple CC designed by K. Zimmerman of this Laboratory, with a variable τ from 0.03 to 1.0 μsec, was used to measure routinely the abundance of Cu in chondrules. For measurement of the doubly coincident 0.51-Mev annihilation γ's of 12.8-hr Cu^{64}, an optimum τ of 0.3 μsec was found, and this τ value corresponds approximately to the light decay life of the NaI scintillation crystals. The width of τ, set by observation of the pulse width on an oscilloscope, was checked by counting the random coincidence rate of the 0.662-Mev γ's (0.61- to 0.71-Mev windows for the SCA) of Cs^{137}. Variable delay lines built in the CC allow precise matching or overlapping of the τ widths for each circuit. For obvious reasons, this circuit will be used for the IPAA of Ni and other radionuclides having coincident γ's.

The abundance determinations resulting from research performed under this contract and other allied researches by the principal investigator and his collaborators during the current contract year have been published in various technical journals, are in press, have been submitted for publication, or have been presented at technical meetings. A list of these papers and presentations is given below.

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*The quarterly progress report for the period ending February 28, 1965.

PAPERS AND PRESENTATIONS

1. Schmitt, R. A., E. Bingham, and A. A. Chodos, "Zirconium Abundances in Meteorites and Implications to Nucleosynthesis," Geochim. et Cosmochim. Acta 28, 1961-1979 (1964).

2. Choy, S. C., and R. A. Schmitt, "Gamma-Ray Spectra Analyzed by Computer Program using the Peak Area Method," Nature 205, 758-760 (1965).

3. Schmitt, R. A., R. H. Smith, and G. G. Goles, "Abundances of Na, Sc, Cr, Mn, Fe, Co, and Cu in 218 Individual Meteoritic Chondrules via Activation Analysis (I)," J. Geophys. Res. 70, 2419-2444 (1965).

4. Schmitt, R. A., R. H. Smith, and L. Haskin, "Abundances of the Fourteen Rare-Earth Elements, Scandium, and Yttrium in the Solar System," in Rare Earth Research, II (K. Vorres, ed.), Gordon and Breach, New York, 1964, pp. 583-621.

5. Schmitt, R. A., R. H. Smith, and G. G. Goles, "Abundances of Trace Elements in Meteoritic Chondrules and Separated Minerals," a talk presented at the meeting of the Meteoritical Society in Tempe, Arizona, October 30-31, 1964.

6. Schmitt, R. A., "Instrumental Activation Analysis of Meteorites," an invited talk presented at the Advanced Seminar on Activation Analysis, San Diego, April 26-28, 1965.

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7. Glendenin, L. E., and R. A. Schmitt, "Neutron-Capture Cross Section of 35-hr Rh^{105}," Nucl. Sci. Eng. 20, 298-301 (1964).

8. Van Lint, V. A. J., M. E. Wyatt, R. A. Schmitt, and C. S. Suffredini, "Range of Photoparticle Recoils, Part II," submitted to the Physical Review, 1964.

Table 1

ABUNDANCES OF Sc, Cr, Fe, AND Co IN ORNANS CHONDRULES (TYPE IIIA CHONDRITE) DETERMINED VIA INAA

Chondrule[a]	Sc (ppm)	Cr (ppm)	Fe (%)	Co (ppm)
1	15.0±1.9	4890±100	3.4±0.7	0
2	16.7±1.5	4640±150	4.5±1.8	320±50
3	8.5±1.7	3240±60	0	390±70
4	5.9±1.7	2800±160	13.7±0.9	350±60
5	10.2±1.5	4830±150	9.3±1.8	400±50
6	7.9±1.3	1860±40	3.3±1.9	200±50
7	10.6±1.3	4090±120	4.1±1.6	360±40
8	8.9±1.3	4360±120	6.9±1.5	480±40
9	2.9±1.3	3290±60	8.2±2.1	460±50
10	6.4±1.3	3550±70	7.8±1.9	570±40
11	10.0±1.0	5400±150	7.0±1.4	160±30
12	9.9±1.2	3360±60	5.0±1.7	380±40
13	25.2±0.8	4840±120	6.5±1.3	500±30
14	12.2±1.4	3710±80	15.4±1.5	780±40
15	7.9±0.7	4700±120	7.9±1.0	210±20
Average	10.5±3.6	3970±800	6.9±2.8	370±130
16	7.9±1.0	5540±100	12.7±1.8	770±40
17	12.5±1.0	4740±90	2.5±1.0	190±20
18	13.4±0.6	5400±100	17.2±1.0	690±20
19	9.4±0.7	2190±40	2.1±0.8	270±20
20	9.4±0.8	3850±80	13.5±0.8	820±20
21	2.4±1.4	3740±80	21.2±1.9	2190±40(out)[b]
22	22.2±0.9	3270±60	6.3±0.7	360±20
23	11.2±0.8	3950±80	16.7±0.8	700±20
24	8.6±0.7	3970±80	10.8±0.8	650±20
25	6.3±0.6	4250±80	12.5±0.9	760±20
Average	10.3±3.6	4690±920	11.6±5.0	580±200
Grand Average	10.5±3.6	4020±760	8.7±4.4	450±190
Chondrite	8.6±0.3	3510±70	27.0±1.2	670±10

[a] All chondrules were magnetic. See Table 6 of GA-6414 for masses of chondrules and for abundance values of Na, Mn, and Cu.

[b] This (out) value is not included in the averages.

Table 2

ABUNDANCES OF Na, Sc, Cr, Mn, Fe, Co, AND Cu IN SARATOV CHONDRULES (L-GROUP CHONDRITE) DETERMINED VIA INAA

Chondrule	Mass (mg)	Na (ppm)	Sc (ppm)	Cr (ppm)	Mn (ppm)	Fe (%)	Co (ppm)	Cu[a] (ppm)
1	0.103	11,600±500	16.0±3.2	3580±100	2740±90	3.9±3.6	200±100	18±36
2	2.00	9,860±200	10.0±2.0	4550±90	3060±60	12.0±0.5	150±10	60±6
3	2.09	7,760±150	8.2±0.5	3320±70	2680±50	9.0±0.5	69±10	74±6
4	2.13	8,330±160	8.3±0.5	4230±80	3180±60	14.5±0.8	220±20	82±6(D)[b]
5	2.61	5,270±100	6.6±0.5	3400±70	3050±60	14.7±0.5	82±8	171±8(D)
						Avg. 10.8±3.5	Avg. 140±60	
6	6.92	6,620±120	6.9±0.5	3730±70	2760±60	12.8±0.5	160±10	89±5(D)
7	6.97	8,920±170	8.7±0.4	3250±60	2760±60	13.5±0.4	110±10	87±14
8	7.14	6,810±130	9.2±0.5	4300±80	3330±60	12.3±0.6	230±10	44±14
9	8.70	6,140±120	7.0±0.4	3080±60	2470±50	15.0±0.6	240±10	97±12
10	16.02	8,600±160	9.3±0.5	3500±70	2660±50	15.9±0.5	350±20	67±9
						Avg. 13.9±1.2	Avg. 220±60	
Average		7,990±1470	9.0±1.7	3690±410	2870±230(±8%)	12.4±2.4	180±70	79±26
11	0.159	5,000±300	17.0±2	2660±50	3450±100	5.4±1.0	0	0.21
12	0.227	31,900±600(out)	20.6±1.0	3840±120	2140±80	4.4±1.1	16±32	91±27
13	0.283	8,430±320	11.0±2	4020±80	3540±80	3.4±0.9	0	6±16
14	0.428	10,700±300	8.7±0.6	4480±90	2980±80	9.9±1.0	6±20	27±15
15	0.440	8,500±320	11.0±3.7	4330±80	3560±70	5.4±1.4	0	12±12
16	0.612	9,210±270	9.7±0.5	3740±80	2930±60	7.7±0.6	12±15	43±13
17	0.910	9,450±270	8.7±0.3	3830±80	2340±40	7.5±0.5	7±10	36±10
18	0.938	6,630±180	9.3±0.6	3870±80	3200±60	7.0±0.7	32±15	36±10
19	0.996	7,960±220	7.7±0.6	4130±80	3460±70	5.8±0.6	2±14	33±9
20	1.18	6,170±180	7.3±0.3	4060±80	3580±70	10.2±0.4	18±8	28±7
21	1.315	6,000±180	11.7±0.4	2920±60	2830±60	13.3±0.5	19±10	71±12
22	1.48	9,020±200	13.4±0.5	2790±60	2990±60	9.5±0.4	0	10±11
23	1.57	8,730±160	10.3±0.4	3680±70	2820±60	6.8±0.5	13±8	37±13
24	1.84	9,750±200	10.8±0.4	3120±60	3280±60	9.7±0.4	5±8	20±11
25	1.98	9,370±200	8.4±0.4	4150±80	3290±60	14.1±0.4	34±7	34±11
		Avg. 8,210±1330	Avg. 11.0±2.5	Avg. 3710±450		Avg. 8.0±2.5	Avg. 11±9	
26	2.31	6,330±120	6.3±0.4	3810±80	4430±80	10.9±0.5	34±8	31±9
27	2.75	8,020±160	7.9±0.5	3270±60	3320±60	8.5±0.5	39±8	42±10
28	2.80	8,580±160	8.3±0.4	4580±90	3670±70	10.7±0.4	42±6	44±11
29	3.09	8,580±170	8.9±0.3	4880±100	3650±70	6.8±0.2	20±4	23±9
30	3.16	5,320±100	7.7±0.3	3200±60	2910±60	14.4±0.3	21±4	23±7
31	3.33	5,150±100	5.6±0.3	2640±60	4140±80	10.8±0.4	43±6	32±8
32	3.49	10,300±200	10.1±0.3	3720±80	2990±60	10.7±0.4	6±4	22±9
33	3.51	2,570±80	8.9±0.5	4790±90	2970±60	11.8±0.4	13±7	11±5
34	3.83	6,400±120	7.6±0.3	5120±50	3920±80	7.8±0.3	0	26±7
35	5.04	7,850±150	8.3±0.3	3470±70	3320±60	12.0±0.4	46±5	56±8
36	5.47	4,820±90	7.9±0.5	4630±90	3690±70	9.5±0.4	39±4	59±7
37	6.39	5,770±120	6.1±0.4	4240±80	3750±70	7.9±0.4	12±6	37±6
38	6.82	8,200±160	8.4±0.3	3860±80	3520±70	12.9±0.4	37±4	46±7
39	8.90	5,880±120	7.5±0.4	4320±80	3370±60	10.4±0.4	36±5	32±5
40	13.64	8,050±160	6.2±0.2	4080±80	3380±60	14.2±0.3	47±3	46±9
		Avg. 8,790±2210	Avg. 7.7±0.9	Avg. 4040±560		Avg. 10.6±1.7	Avg. 29±14	
Average		7,470±1610	9.4±3.1	3880±510	3310±360	9.3±2.5	20±15	34±14
Grand Average		7,620±1570	9.3±2.0	3830±490	3200±380	10.1±2.8	60±60	45±23

[a] Cu was counted via coincidence counts of the 0.51-Mev annihilation γ's of 12.8-hr Cu^{64}, using two 2 in. × 2 in. NaI crystals and two SCA with 0.46- to 0.56-Mev windows. The CC was used with a τ of 0.3 μsec, i.e., $2\tau = 0.6$ μsec.

[b] (D) stands for the average value of two abundance determinations separated by a decay of four half-lives.

Table 3

ABUNDANCES OF Na, Sc, Cr, Mn, Fe, Co, AND Cu IN RICHARDTON CHONDRULES (H-GROUP CHONDRITE) DETERMINED VIA INAA

Chondrule	Mass (mg)	Na (ppm)	Sc (ppm)	Cr (ppm)	Mn (ppm)	Fe (%)	Co (ppm)	Cu[a] (ppm)
1	0.392	11,600±500	3.7±0.9	3660±70	2890±60	7.1±0.5	0±24	50±12
2	0.406	8,130±320	12.1±0.8	3540±70	3250±60	5.3±0.6	0±24	19±10
3	0.463	8,040±320	13.8±1.0	3040±60	2740±60	7.6±0.9	68±23	61±11
4	0.758	7,070±280	7.5±0.4	4810±90	3180±60	8.4±0.4	48±10	26±7
5	0.792	7,930±320	11.9±0.4	3500±70	3010±60	8.8±0.5	20±10	64±9
6	0.974	18,800±600(out)[b]	9.3±0.6	11,900±200(out)	2300±40(out)	7.7±0.6	29±10	49±11
7	0.980	20,600±700(out)	8.2±0.6	6760±120	2150±40(out)	7.8±0.8	21±15	77±13
8	1.09	5,490±220	12.1±0.6	5750±100	3280±60	7.6±0.7	40±14	32±6
9	1.17	9,150±360	15.1±0.6	3666±80	2920±60	7.4±0.3	24±6	47±8
10	1.28	7,260±280	11.5±0.6	3430±70	3120±70	6.7±0.5	23±11	42±7
Average		8,080±1160	10.5±2.7	4250±1030	3050±160(±5.2%)	7.4±0.6	27±14	47±14
11	1.40	6,030±240	5.0±0.4	4820±100	2850±60	15.2±0.5	118±10	106±8(D)[c]
12	2.08	7,980±320	8.5±0.3	4230±80	2960±60	10.2±0.4	42±5	58±6
13	2.53	8,370±320	19.5±0.7	2420±50	2730±60	9.3±0.4	3±3	39±5
14	2.74	6,600±250	4.9±0.3	4240±80	3000±60	12.2±0.5	18±4	79±5
15	2.96	7,040±280	12.9±0.4	3790±80	2910±60	9.0±0.4	50±6	23±5
16	3.07	8,220±320	17.9±0.4	2360±50	2730±60	10.0±0.4	20±4	33±5
17	4.14	7,630±300	11.5±0.4	3180±60	2840±60	9.8±0.4	31±6	33±3(D)
18	7.11	5,620±200	12.9±0.4	2840±60	3030±60	9.4±0.2	31±3	23±5(D)
19	7.40	5,900±200	11.1±0.3	3620±70	3070±60	8.5±0.3	31±4	33±2(D)
20	9.98	2,630±100(out)	8.2±0.3	5000±100	3260±60	10.6±0.3	41±4	21±2(D)
Average		7,050±900	11.2±3.7	3650±770	2940±130(±4.4%)	10.4±1.3	39±21	45±22
Grand Average		7,530±1090	10.9±3.2	3930±850	2990±150(±5%)	8.9±1.6	33±18	46±18

[a] Cu was counted via coincidence counts of the 0.51-Mev annihilation γ's of 12.8-hr Cu^{64}, using two 2 in. × 2 in. NaI crystals and two SCA with 0.46- to 0.56-Mev windows. The new CC was used with a τ of 0.3 μsec, i.e., $2\tau = 0.6$ μsec.

[b] The (out) values are not included in the averages.

[c] (D) stands for the average value of two abundance determinations separated by a decay of two half-lives.

Table 4

ABUNDANCES OF Na, Mn, AND Cu IN MILLER CHONDRULES (H-GROUP CHONDRITE) DETERMINED VIA INAA

Chondrule	Mass (mg)	Na (ppm)	Mn (ppm)	Cu[a] (ppm)
1	0.189	7,740±150	2740±50	66±16
2	0.537	16,000±300(out)[b]	2570±50	26±13
3	0.712	6,900±140	2770±50	55±9
4	0.872	9,320±180	2620±50	49±9
5	0.93	24,300±500(out)	1920±50	52±16
6	1.025	9,140±180	2620±50	89±10
7	1.29	8,000±160	2740±50	17±7
8	1.59	8,720±160	2310±50	0±6
9	1.77	9,400±180	2500±50	39±7
10	1.86	6,900±140	2570±50	38±5
Average		8,270±880		43±19
11	2.30	7,300±140	2650±50	65±6
12	2.52	8,570±160	2660±50	29±6
13	2.77	8,250±160	2830±50	26±5
14	3.24	8,010±160	2620±50	66±5
15	4.03	7,920±160	2710±50	52±5
16	5.09	8,960±160	2560±50	17±4
17	5.48	8,150±100	2790±50	4±4
18	6.46	4,320±80	2950±60	46±3
19	6.50	5,680±100	2330±60	28±4
20	27.1	6,460±120	2400±50	26±2
Average		7,360±1140		36±17
Grand Average		7,770±1080	2590±160(±6%)	40±19

[a] Cu was counted via coincidence counts of the 0.51-Mev annihilation γ's of 12.8-hr Cu^{64}, using two 2 in. × 2 in. NaI crystals and two SCA with 0.46- to 0.56-Mev windows. The new CC was used with a τ of 0.3 μsec, i.e., 2 τ = 0.6 μsec.

[b] The (out) values are not included in the averages.

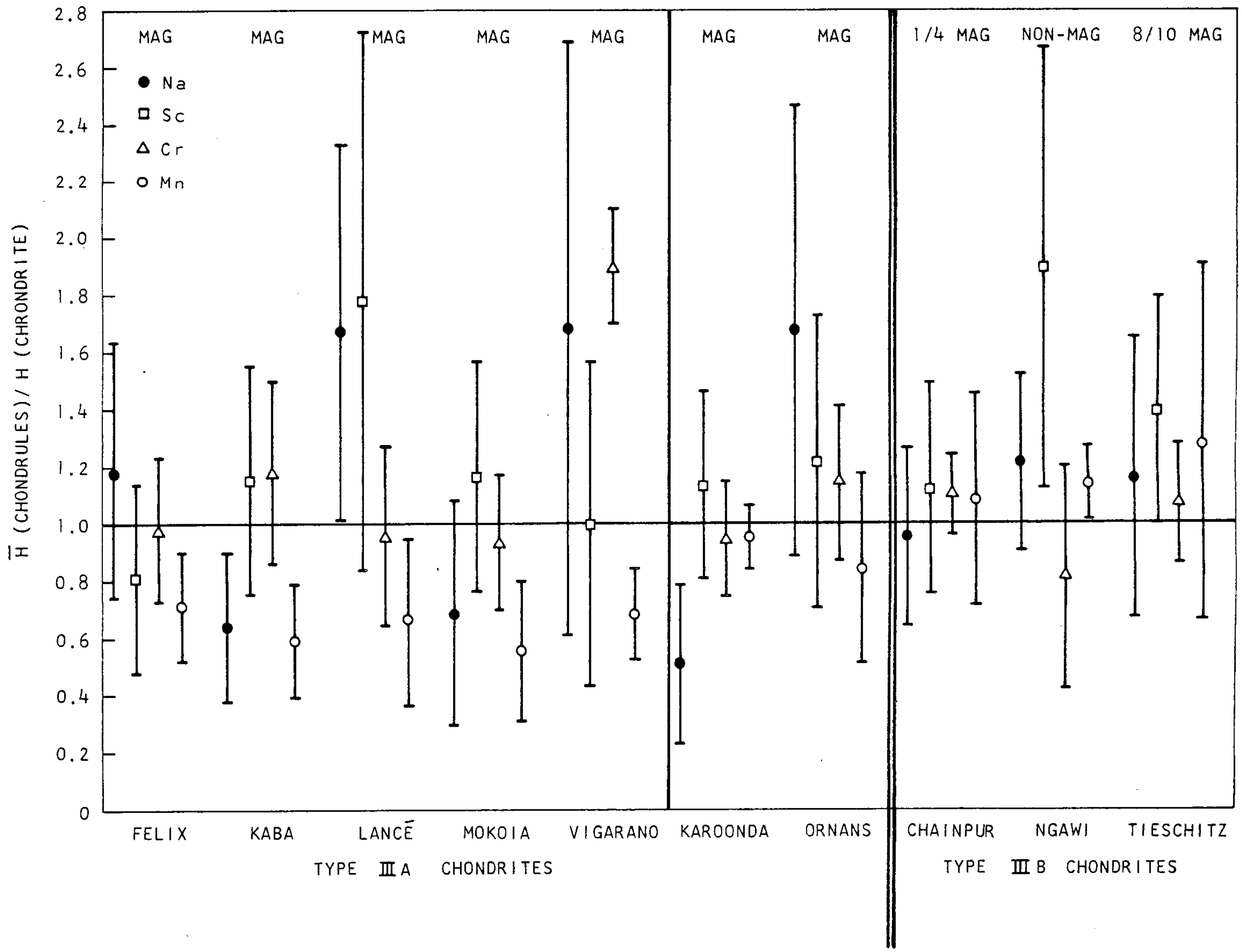

Fig. 1--Ratios of elemental abundances of Na, Sc, Cr, and Mn in chondrules to abundance in chondrite; spreads are root mean square of abundances in chondrules

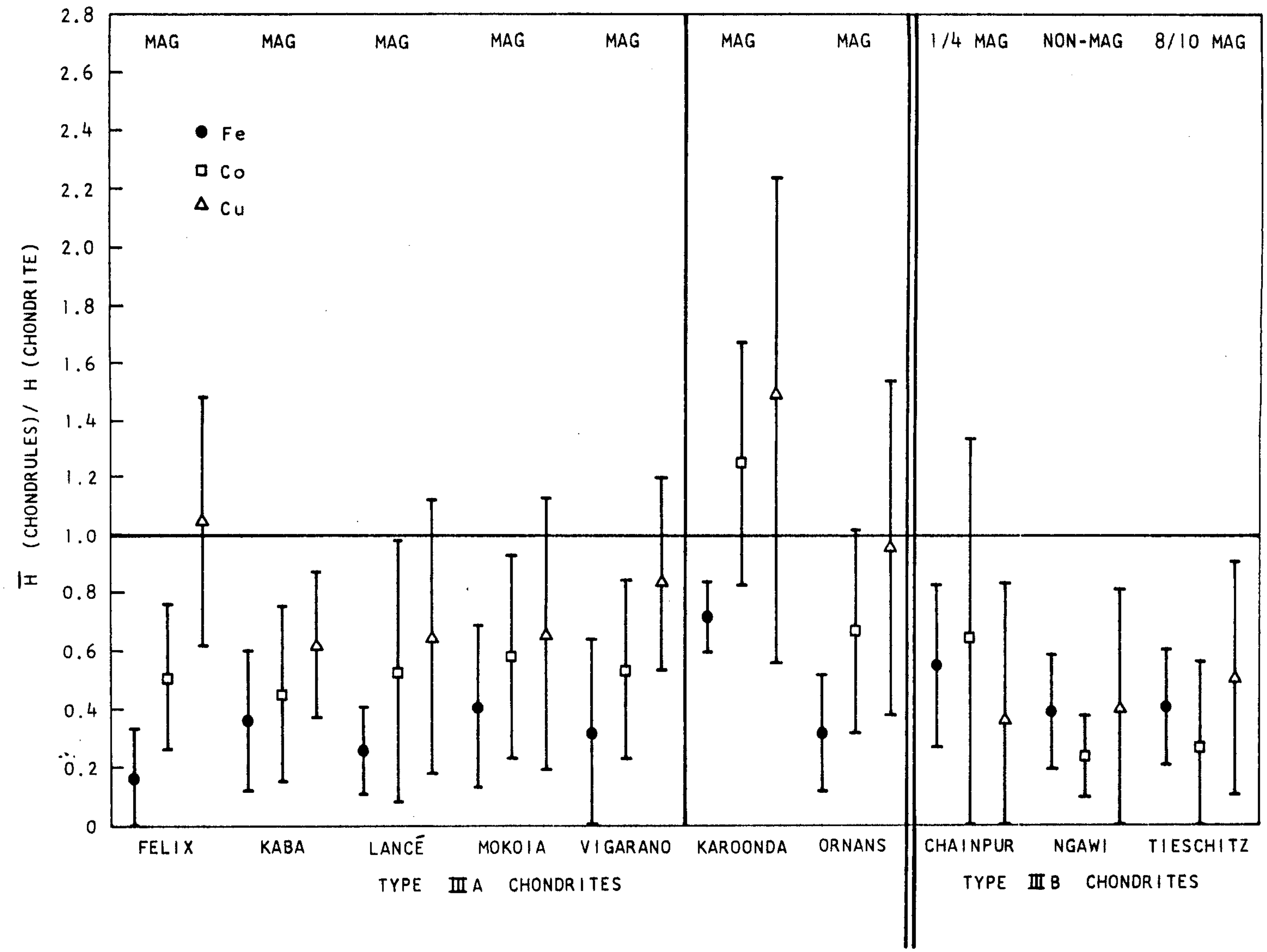

Fig. 2--Ratios of elemental abundances of Fe, Co, and Cu in chondrules to abundance in chondrite; spreads are root mean square of abundances in chondrules

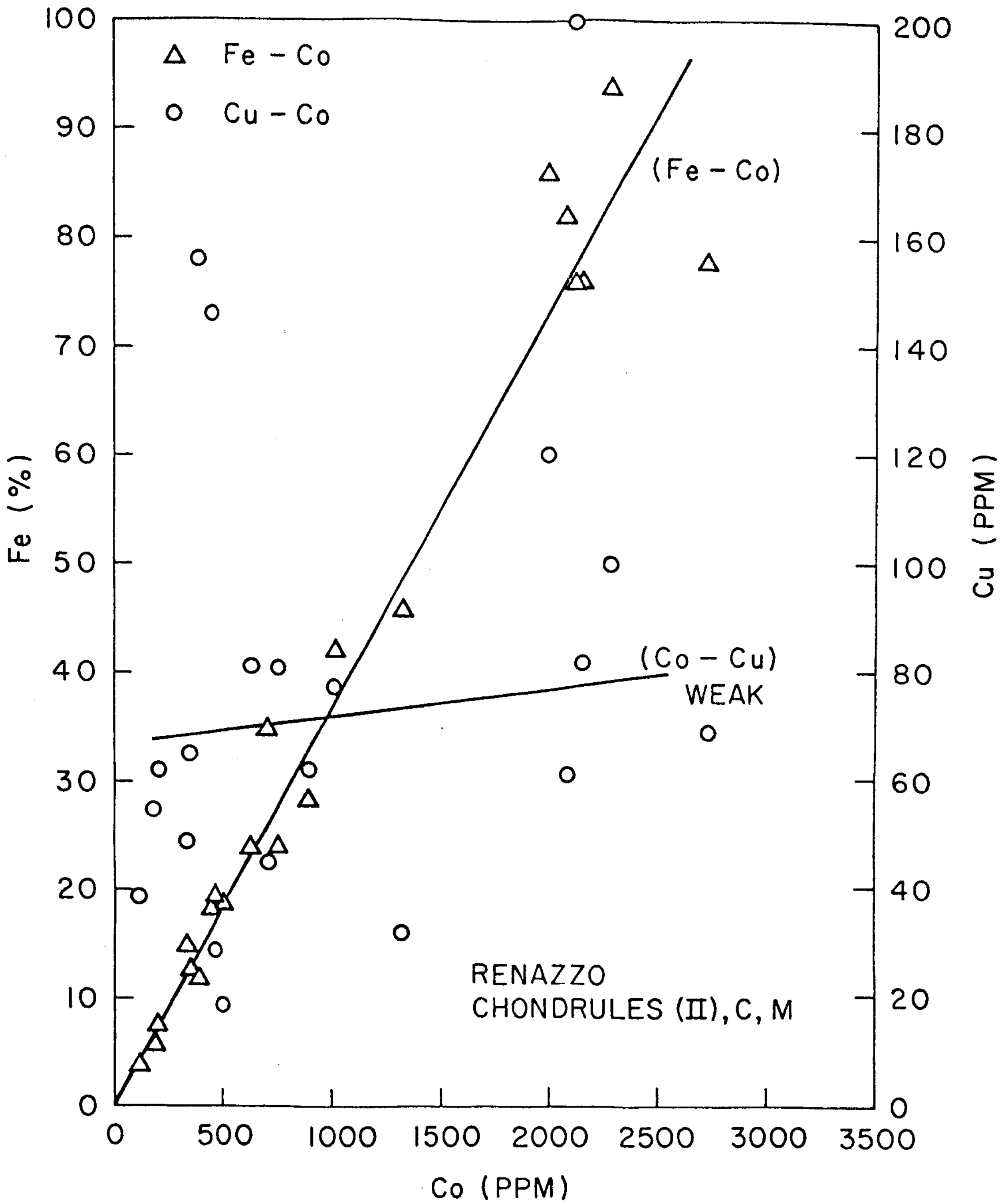

Fig. 3--Correlations of Fe-Co and Cu-Co in 21 Renazzo (Type II) carbonaceous magnetic chondrules

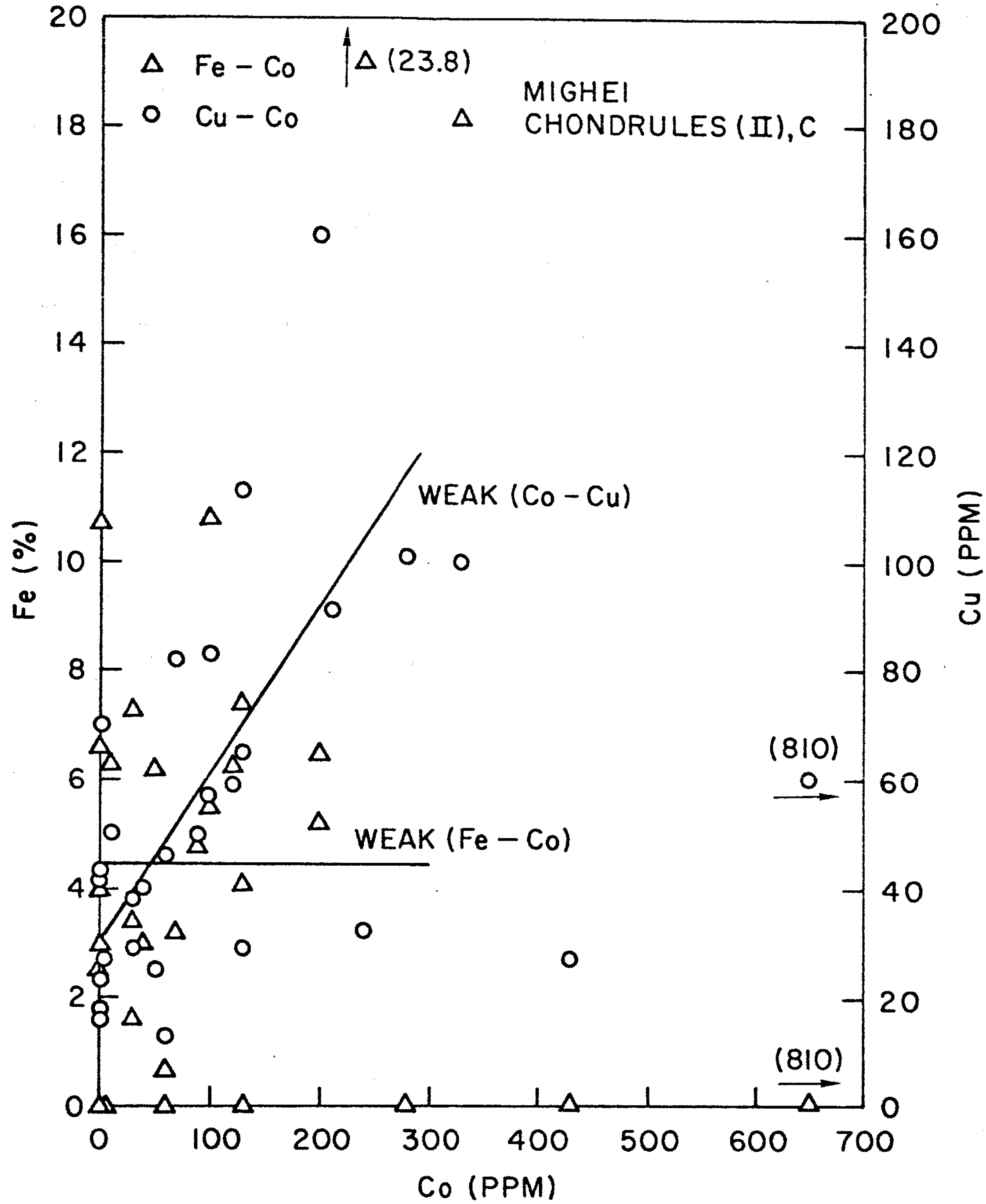

Fig. 4--Correlations of Fe-Co and Cu-Co in 30 Mighei (Type II) carbonaceous chondrules

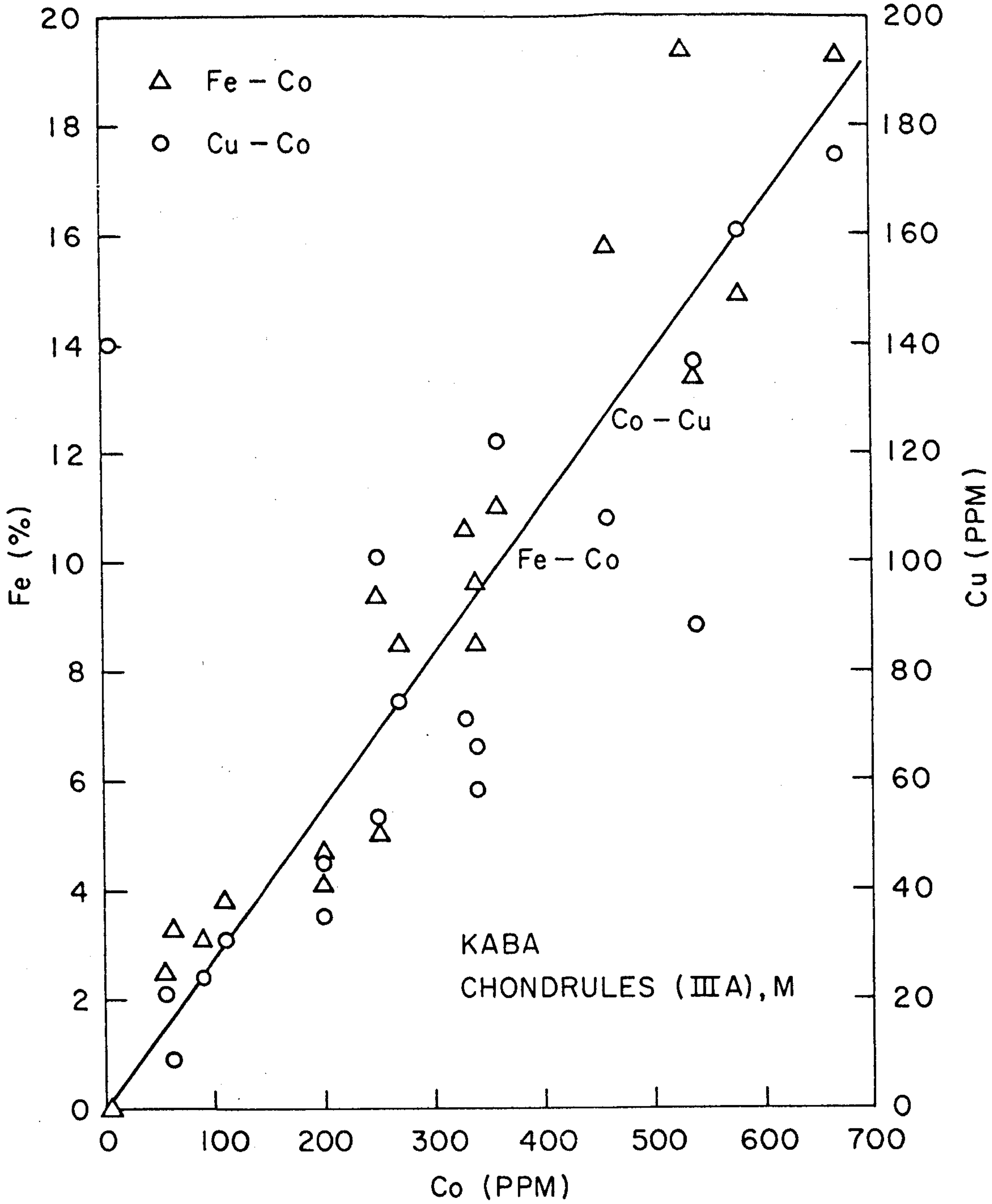

Fig. 5--Correlations of Fe-Co and Cu-Co in 20 Kaba (Type IIIA) chondrules

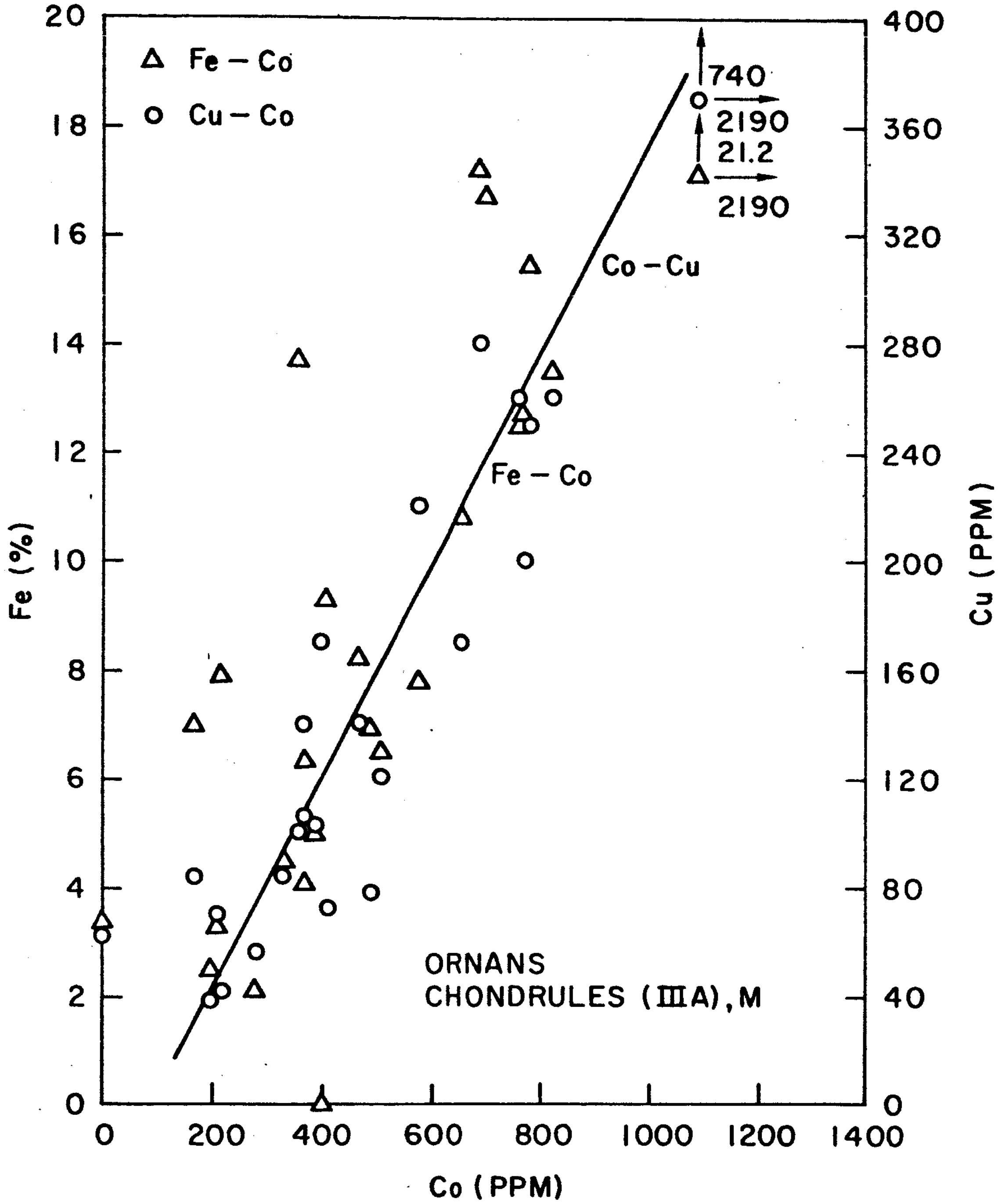

Fig. 6--Correlations of Fe-Co and Cu-Co in 25 Ornans (Type IIIA) chondrules

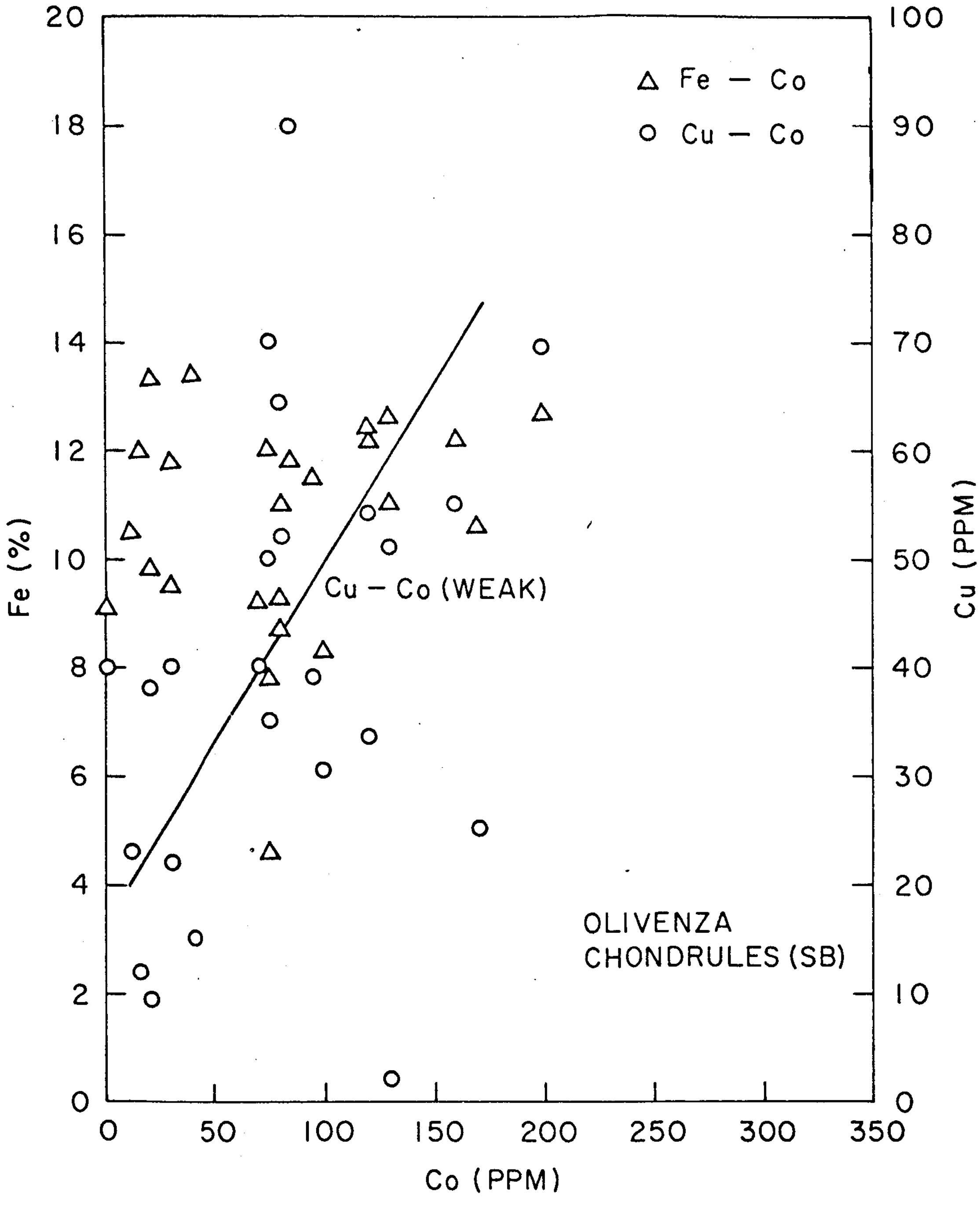

Fig. 7--Correlations of Fe-Co and Cu-Co in 25 Olivenza (Soko-Banjitic) chondrules